UNCLASSIFIED

AD NUMBER
AD529743
CLASSIFICATION CHANGES
TO: unclassified
FROM: secret
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; DEC 1973. Other requests shall be referred to Director, Naval Research Lab., Washington, DC 20375. NOFORN. REL TO UK.
AUTHORITY
NRL Code/5309 memo dtd 20 Feb 1997; NRL Code/5309 memo dtd 20 Feb 1997

THIS PAGE IS UNCLASSIFIED

AD- 529743

SECURITY REMARKING REQUIREMENTS

DOD 5200.1-R, DEC 78

REVIEW ON 21 DEC 93

12,592

AD529743

"NATIONAL SECURITY INFORMATION"
"Unauthorized Disclosure Subject to Criminal Sanctions"

SECRET-NOFORN
EXCEPT UK

NRL Report 7655
Copy No. 65

The Subtle but Significant Effect of Meteor Echoes on OTH-Radar-System Detection Sensitivities

[Unclassified Title]

FRANK H. UTLEY, WILLIAM C. HEADRICK,
DERRILL C. ROHLFS, AND JAMES A. HOFFMEYER

Radar Techniques Branch
Radar Division

December 21, 1973

SPECIAL HANDLING REQUIRED
NOT RELEASABLE TO FOREIGN NATIONALS EXCEPT UK

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECRET-NOFORN
EXCEPT UK

SECRET, classified by DIRNRL.
Exempt from GDS of E.O. 11652 by DIRNRL.
Ex. Cat. (3). Auto declass. Dec. 31, 2003.

Distribution limited to U.S. Government Agencies only; test and evaluation; December 1973. Other requests for this document must be referred to the Director, Naval Research Laboratory, Washington, D.C. 20375.

SECRET

NATIONAL SECURITY INFORMATION

Unauthorized Disclosure Subject to Criminal Sanctions.

SECRET

SECRET-NOFORN EXCEPT UK

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 7655	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE SUBTLE BUT SIGNIFICANT EFFECT OF METEOR ECHOES ON OTH-RADAR-SYSTEM DETECTION SENSITIVITIES		5. TYPE OF REPORT & PERIOD COVERED An interim report on one phase of a continuing NRL Problem. 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Frank H. Utley, William C. Headrick, Derrill C. Rohlfs, and James A. Hoffmeyer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem R02-42 USAF MIPR FY76207300001 to NRL 3/19/73
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Air Force HQ ESD, L.G. Hanscom Field, Bedford, MA 01730		12. REPORT DATE December 21, 1973 13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Secret-Noforn Except U.K. 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE XGDS-(3)-03

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government Agencies only; test and evaluation; December 1973. Other requests for this document must be referred to the Director, Naval Research Laboratory, Washington, D.C. 20375.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

OTH Radar
Meteors
FPS-95
Ionosphere

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(Secret-Noforn Except U.K.)

This report investigates the possibility that meteor-nose echoes are a causative mechanism for noise currently being observed on the FPS-95 radar. A description of the noise is given as documented by on-site observers. Meteor-nose echoes are postulated as being partly responsible for the observed noise. Recent Madre Measurements have permitted a difinition of the spectral character of the meteor-nose echo both in the near and far ranges. Spectral examples

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECRET-NOFORN EXCEPT UK

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Continued

of each are given. The spectral behavior of the meteor-nose echo agrees very well with that of the FPS-95 noise. Theoretical tenets as well as experimental evidence force the conclusion that the FPS-95 noise is produced in part by meteor-nose echoes.

CONTENTS

THE SUBTLE BUT SIGNIFICANT EFFECT OF METEOR ECHOES ON OTH-RADAR-SYSTEM DETECTION SENSITIVITIES

[Unclassified Title]

INTRODUCTION

(S) The Naval Research Laboratory has been active in the development of OTH radar technologies since the early 1950's. Over the years detections have been achieved of nuclear detonations, missile-induced ionospheric perturbations, aircraft, hypervelocity reentry bodies, ships, and IRBM, SLBM, ICBM and ABM launches.

(S) As a result of experimental expertise developed at NRL coupled with notable detection success with the Madre radar, the Air Force invited NRL to participate in developing the concepts of the FPS-95 radar. As a follow-on, an NRL team of scientists and engineers helped prepare performance specifications for the FPS-95, evaluated bidding documents, and followed the development of hardware from shortly after contract award until installation at Orfordness, East Anglia, United Kingdom. NRL has had a team of research investigators on site for the past 2-1/2 years. NRL continues to have vested interest in the successful operation of the FPS-95 radar.

(S) The FPS-95 radar system is perhaps unique, possessing greater transmitter purity and receiving system linearity, resulting in greater sensitivity, than any other known OTH radar system. The receiver linear range of 90 dB has permitted the detection of minimal echoes perhaps heretofore not seen by extant OTH systems. This great system sensitivity however has produced a wide gamut of effects to be seen in the radar output, thus often compromisingthe range of visibility from 90 dB to 70 or even 60 dB. On-site scientists have been diligent in ferreting out various trouble spots in the hardware such as in the signal processor, antenna, and antenna ground screen. As defects are located, fixes are installed. These improvements have in fact resulted in greater linearity.

(S) Presently under investigation at the FPS-95 site is the propagation medium. It is likely that received signals heretofore termed noise may be due to range-discrete meteor echoes or to range-dispersive auroral scatterers. It is the purpose of this reporting to discuss the possibility of meteor-nose echoes being a contributor to the FPS-95 noise.

(S) Initially in this report a description of the FPS-95 noise will be given as to its distribution in range and associated spectral character. Then an examination in the light of the literature and past NRL experimental experience will be given of the likelihood that meteor-nose echoes can cause the FPS-95 noise. This examination qualifies meteor-nose echoes as a valid possible cause.

(S) Recently the Madre radar was deployed to sample near-range and far-range meteor returns in order that their spectral nature be assessed. These results will be

Manuscript submitted September 4, 1973.

compared with the features of the FPS-95 noise. Good agreement confirms the postulate that meteor-nose echoes are contributors to the FPS-95 background noise. Recommendations will be made as to hardware modifications and operational procedures to minimize meteor nose echoes in the target region.

BACKGROUND

(S) A visit to the FPS-95 radar site was made in December 1972 [1] to determine the nature of the troublesome noise. Even though profitable discussions were held with other NRL scientists, representatives of the Mitre Corporation, Air Force Cambridge Research Laboratory (AFCRL) and members of the Royal Air Force and U.S. Air Force, a lucid description of the noise was not forthcoming. Prior to the conclusion of the visit, consultations were held with the Mission Director, Lt. Col. Wubker [2], during which noise mechanisms were cited by NRL, these being: near-range and far-range, meteor echoes, a round-the-world echoes, spurious-lobe (off-axis) auroral echoes, precipitation static, echoes (doppler dispersed) from field-aligned irregularities at or near the magnetic equator, and co-channel interference.

(S) In January 1973 a meeting was held at the Mitre Corporation in Bedford, Massachusetts, to discuss possible mechanisms for the noise. At this meeting the first clear characterization of the noise was given [3]. NRL was referred to an internal Mitre memorandum [4] and was subsequently supplied a copy of the memorandum. The description of the noise given is as follows:

- The noise varies markedly with range; it is not uniformly distributed over all range bins as noise should be.

- The noise seems to be prominent at near ranges, with a null occurring at 600 to 700 n.mi. and a rise in noise level occurring 100 or more nautical miles in front of the earth backscatter; hence the name range-related noise (RRN). RRN is seen in different seasons, at different times of the day, in various beams, on both polarizations, and at various operating frequencies. The near-range noise (out to approximately 600 n.mi.) persists even when the operating frequency is above the maximum usable frequency (above the MUF no ionospheric refraction is available).

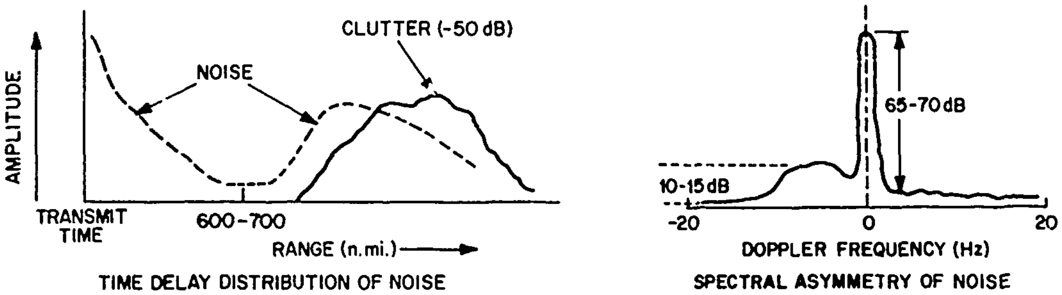
- The noise tends somewhat to be proportional to ground-clutter amplitude, hence the name clutter-related noise (CRN) as well as RRN.

- The energy is spread into doppler domains well removed from the normal clutter spectrum.

- The noise level is asymmetric between approaching and receding doppler bins; at near ranges and far ranges in front of the earth backscatter the noise energy evidences a shift to the recede dopplers.

(S) Figure 1 depicts the dominant features of the noise being seen with the FPS-95 radar. In fig. 1a the clutter (earth return) has been reduced by 50 dB to effect a

comparison in range of appearance of the noise and clutter. The dotted line representing the noise has a minimum between 600 and 700 n.mi. The noise measured at the null is at a level that is expected. The enigma that persists is that such a low level of noise is not available at all ranges. The noise can be seen to rise from the null at a range in advance of the earth return.



(S) Fig. 1—Description of noise detected with the FPS-95 radar (a) Time-delay distribution of the noise showing the basis for the names clutter-related noise (CRN) and range-related noise (RRN) (b) Spectral asymmetry of the noise

(S) Figure 1b shows the spectral character of the CRN. The large echo at 0 doppler frequency corresponds to the clutter. It can be seen that approach (positive) dopplers show a flat response from the clutter edge out to maximum dopplers whereas the energy of the recede side of the carrier shows a 10 to 15 dB rise above the 65 to 70 dB down level.

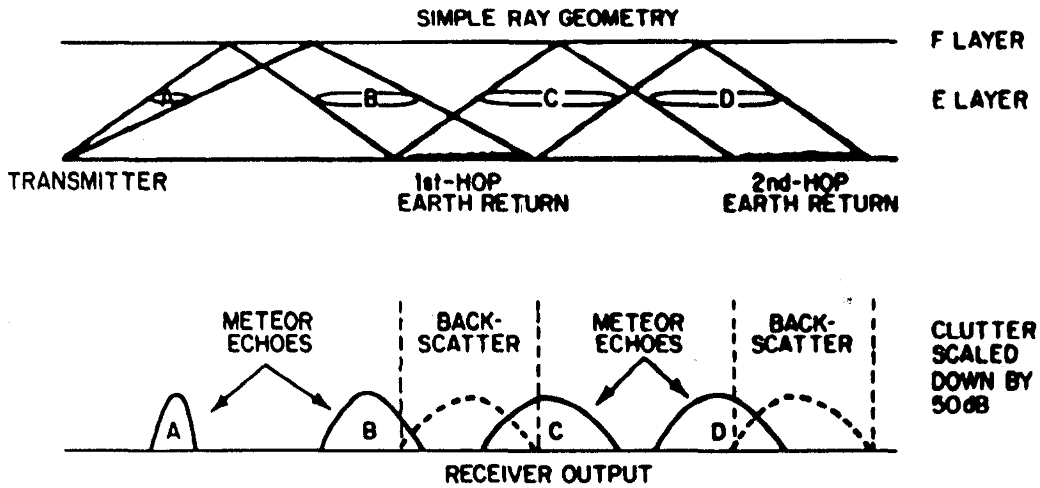
HYPOTHESIS OF A NOISE MECHANISM

(S) NRL's immediate reaction to the description of the RRN as given at the Mitre Corporation in January was that meteor-nose echoes were in a good part responsible for the noise. The radar ray profile shown at the top in Fig. 2 repeatedly intersects with the *E* layer. The region over which meteors impacting the earth's atmosphere ionize is centered approximately around 100 km, which coincides essentially with the *E* layer [5-8]. Each penetration of the *E* layer gives rise to many meteor echoes both of the nose and trail types.

(S) The meteor-nose echoe is due to radar energy being reflected from the volume of electrons being produced during the formation of the trail and is available for a fractional part of a second. The meteor-trail echo, which in contrast to the meteor-nose echo may persist for seconds or even minutes, is energy reflected from the ionized trail of a meteor after the meteor itself has essentially consumed itself in generation of light, heat, and ionization. The trail echo can possess discrete nonzero dopplers which can be identified with ionospheric winds. The trail echo as it persists will evidence fading due to wind shears in the *E* layer that will tend to disperse the ionized trail.

(S) Not all meteors that produce a nose echo will produce a lasting trail echo. Whether a meteor giving rise to a nose-type echo will generate a trail is a function of ionization levels produced, which in turn depend on particle mass and velocity. It is a redeeming feature for OTH radars that the transient behavior of the nose echo, which predominates in occurrence, does not persist. For this reason integration or dwell times should be chosen to deny the ill effects of meteors without compromising detection sensitivities to a great degree. Although OTH radars are sensitive to both kinds of echoes, consideration to follow will be of the meteor-nose echo alone.

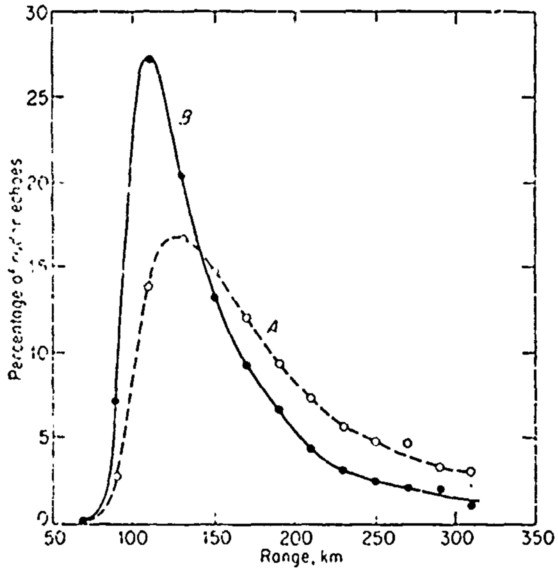
(S) Figure 2 shows the ranges at which meteor echoes as well as clutter appear. It can be seen that meteor-echo distributions essentially bracket the regions of earth returns. The geometry shows that meteor echoes are elicited from the E layer at ranges beginning with the highest ray intersection with the E layer and continuing to the lowest ray of the transmitter beam. Often the lowest ray of the beam is the ray tangent to the earth at the transmitter. This tangent ray intersects the E region at a range of approximately 600 n.mi. Meteors that produce reflections at layer heights above the E layer may give echo ranges in excess of 600 n.mi. The geometry does however support the contention that meteor echoes essentially cease at 600 n.mi. or so. This looks strikingly like the noise null of Fig. 1a.



(C) Fig. 2—Radar ray profile depicting meteor-echo regions: A is the near-range meteor region, B is the far-range region, and C and D are additional regions

Near-Range Meteor Echoes

(U) Figure 3 due to McKinley [9] is a plot of range distributions taken during non-shower observing periods. Curve A for 0600 hours shows a greater percentage of meteors at longer ranges than curve B for 1800 hours. This is because meteors impacting the earth's atmosphere in the morning have added to their velocity the velocity of the earth around the sun, thus giving them a higher velocity, which results in the meteors ionizing at a higher altitude and thus being seen at greater ranges. Those particles inbound at 1800 hours are effectively chasing after the earth; their velocities are reduced by the



(U) Fig. 3—Typical near-range meteor-echo occurrence as a function of radar range (figure from Ref. 9). Curve *A* is for 0600 hours, and curve *B* is for 1800 hours

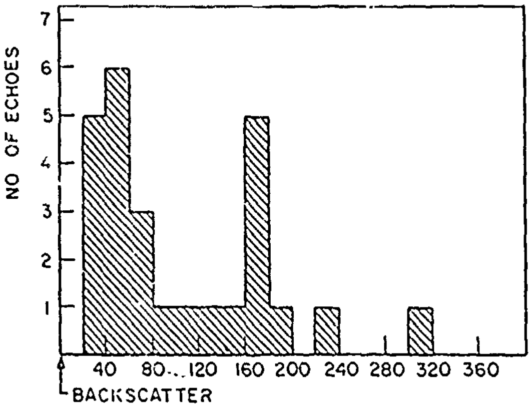
earth's orbital velocity. This visibility differential between the morning and evening meteors accounts for the variation in rates at the two times. The variation is less than an order of magnitude.

(S) Many experimenters [5, 9-11] have documented the presence of meteor echoes in the near range out to the tangent ray. McKinley's plots do not show meteors at 600 n.mi. due presumably to poor low-elevation-angle performance of his antennas.

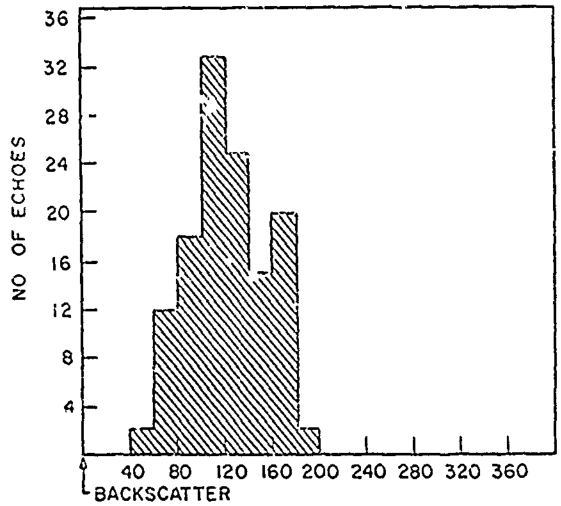
Far-Range Meteor Echoes

(U) Figure 4 gives the far-range meteor distribution [12] for various days in the summer of 1960 as measured using NRL's low-power transmitting equipment. These meteor counts were made from film records showing echoes as a function of range and time. The range parameter was scaled as a separation distance from the ground backscatter. The range bin width was 20 n.mi. No count was made in the 20-n.mi. bin just preceding the backscatter. Even though a doppler analysis was not available to discriminate meteor echoes occurring at ranges coincident with the earth-return pattern, numerous such echoes were seen in the A-scope monitor. The presence of far-range meteor echoes at ranges in advance of first-hop earth returns has been confirmed again and again by various investigators [13-15].

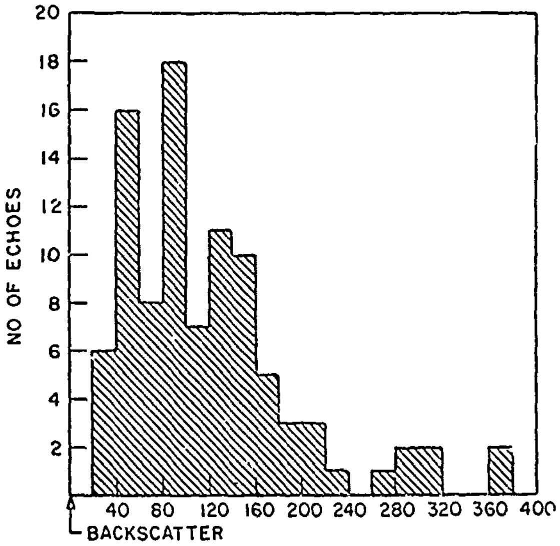
(S) Thus we have seen that near-range and far-range meteor echoes occur at those ranges where the FPS-95 radar noise seems to be at a high level. Next we will establish a characterization of the meteor-nose echo that will show it to coincide spectrally with the asymmetrical noise feature.



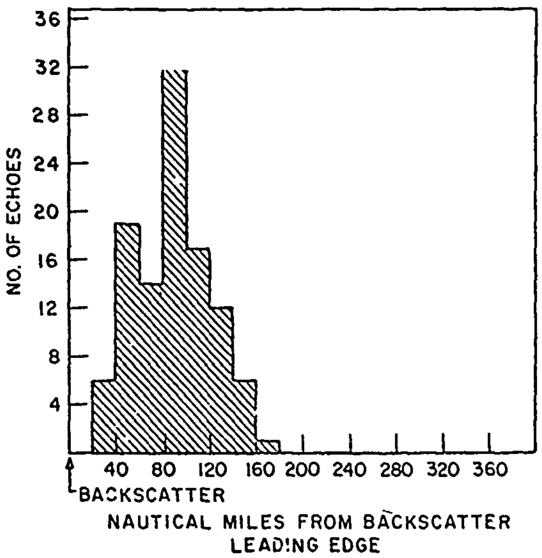
(a) Distribution of June 19, 1960 (centroid 124 n.mi. from the backscatter leading edge at 1797 n.mi.)



(b) Distribution of June 26, 1960 (centroid 122.5 n.mi. from the backscatter leading edge at 1650 n.mi.)

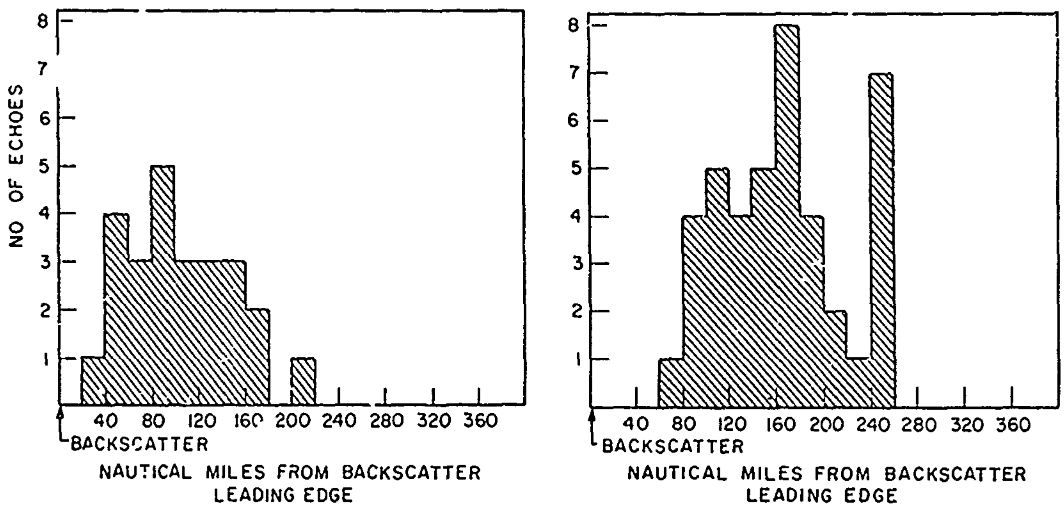


(c) Distribution of July 26, 1960 (centroid 119.5 n.mi. from the backscatter leading edge at 1627 n.mi.)



(d) Distribution of August 1, 1960 (centroid 88.7 n.mi. from the backscatter leading edge at 1475 n.mi.)

(U) Fig. 4—Far-range meteor distributions (no inverse range compensation used)



(e) Distribution of August 6, 1960 (centroid 100.8 n.mi. from the backscatter leading edge at 1538 n.mi.)

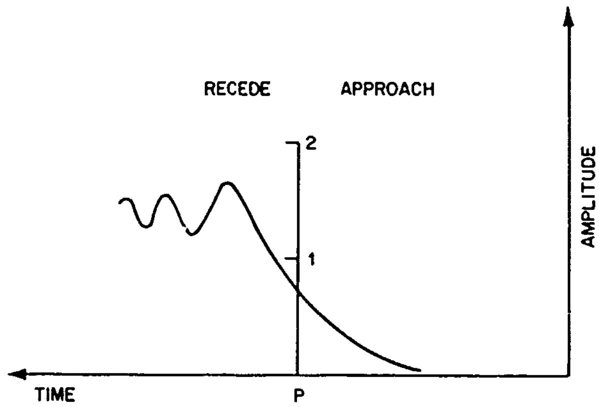
(f) Distribution of August 30, 1960 (centroid 165.3 n.mi. from the backscatter leading edge at 1894 n.mi.)

(U) Fig. 4—(Continued)

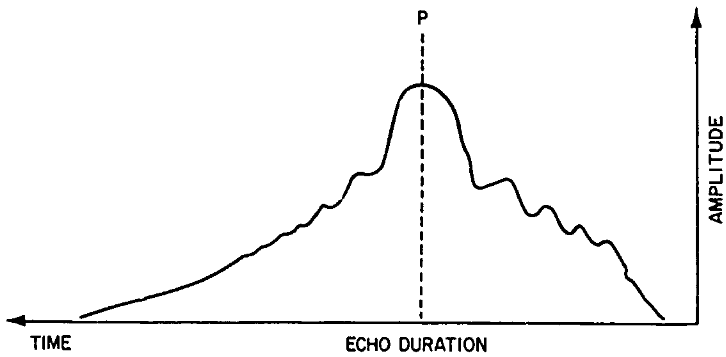
Spectral Character of Meteor-Nose Echoes

(S) Figure 5 due to Lovell [10] shows the theoretical amplitude-vs-time pattern for a meteor-nose echo. The original work for showing the diffraction pattern was performed by Davies and Elyett [16]. The point *P* at the base of the vertical scale represents the point in time (consider the abscissa as a time scale increasing from right to left) that the meteor path becomes perpendicular to the radar ray. The meteor while to the right of the vertical scale axis is an approaching reflector. (Meteor motion is from right to left.) Upon passing the perpendicular (orthogonal geometry between path and ray) the meteor becomes a receding reflector. It can be seen that the echo amplitude grows from a small value on the approach side to a maximum value at a point somewhat beyond point *P*. Thus the meteor-nose echo would yield its largest radar echo after passing point *P* and becoming a receding reflector.

(U) Figure 6 due to Hawkins and Brown [17] shows the theoretical approach and recede character for the meteor nose-echo. The maximum echo amplitude occurs at the time of perpendicularity according to Hawkins. He indicates the rising characteristic is available in only 5% of meteors—that is, there is no appreciable echo energy before the point of orthogonal geometry (also the minimum range point). Hawkins thus seems to corroborate Davies and Elyett in their diffraction-pattern specification for the temporal behavior of the nose echo.



(U) Fig. 5—Theoretical amplitude-vs-time pattern for a meteor-nose echo



(U) Fig. 6—Fresnel-echo notation for a meteor-nose reflection

(U) Manning et al. [18] report a large increase in signal strength of the meteor echo as the received doppler frequency (down whistle for an approaching particle) passes through zero. The maximum signal, termed "burst," is associated with a body doppler frequency which is of the recede sense.

(S) Hence theoretically the meteor-nose echo should present more reflected energy at recede dopplers. If this is experimentally so, the meteor-nose echo becomes a better candidate as the noise causative mechanism. The doppler sense of the maximum-amplitude echo as specified by the theory is in complete accord with the spectral characterization given (Fig. 1) for the RRN. Thus still to be demonstrated by experimental results is that the meteor nose in fact does yield a doppler asymmetrical echo.

EXPERIMENTAL RESULTS

(S) To investigate the spectral character of meteor-nose echoes, on 23 February 1973 the Madre radar was operated on a frequency of 18.100 MHz, which would provide

for above-the-MUF operation for a period of time and then refracted propagation in order that a sampling might be made of the near-range and far-range echoes in one day.

Near-Range Meteor Echoes

(S) The Madre transmitter was operated at progressively lower power levels over the period of the near-range study to see if there was any power dependence of spectral behavior of the meteor. The transmitter power program was as follows:

Time (GMT)	Peak Transmit Power (MW)	Relative Power (dB)
11:04:56—11:15:56	2.3	-3
11:15:56—11:26:56	1.15	-6
11:26:56—11:37:56	0.29	-12
11:39:56—11:50:56	0.073	-18

No modifications in average spectral character of the meteor nose echo was noted as a result of transmitter power changes.

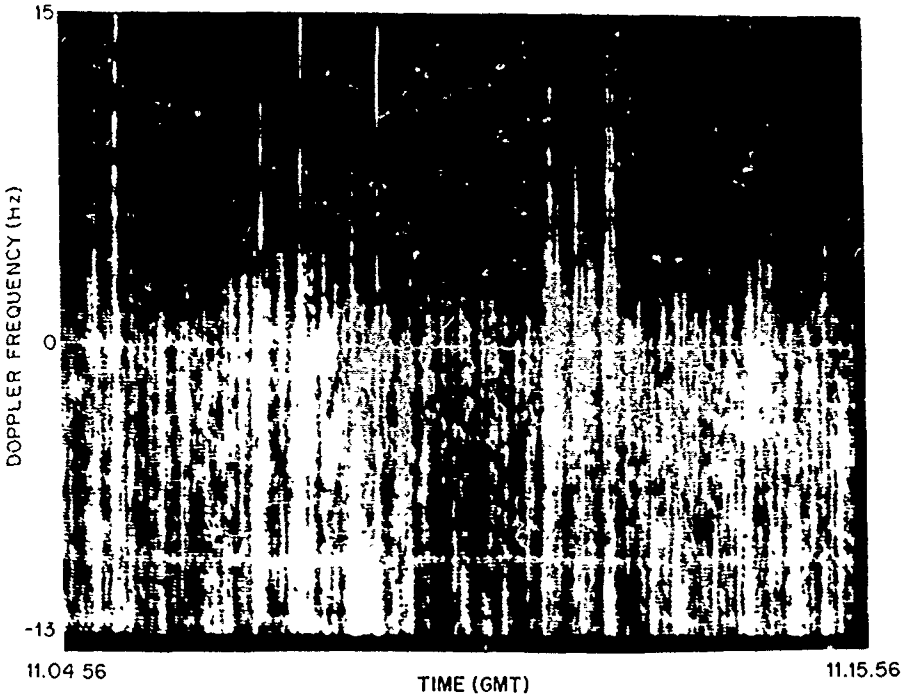
(C) The Madre phased-array antenna was used on boresight (77°T). No modifications were made to azimuth or elevation steering during either the near-range or far-range collection of data.

(S) Figures 7 through 10 are a series of offset doppler time records (11 minutes long) with accompanying spectral readout records. The radar pulse rate for these figures was 60 pps, giving 30 Hz unambiguous doppler. A doppler offset of 15 Hz was used to give 15 Hz above the doppler zero and 13 Hz below (the lower 2 Hz being denied by the display sweep program). Figure 7a is the radar readout from 11:04:56 to 11:15:56. Approach dopplers appear in the upper half of the frame, with recede dopplers appearing below the midpoint on the ordinate.

(S) The range window for these observations was set at 80 n.mi. to simulate the range bin used with the FPS-95 radar on a PRF of 40 pps. NRL feels such a range aperture is too long to discriminate the discrete targets of dimensions that are appreciably less than 80 n.mi.

(S) Each of the vertical intensified lines is a meteor-nose echo. Often more than one echo occurs at the same point (approximately) in time in any given 80-n.mi. range segment. The gross effect noted in Figs. 7a, 8a, 9a, and 10a is the preponderance of meteor echo energy on the lower half or recede side of the record. A majority of the meteor echoes give receding reflections, a smaller number show energy on both approach and recede sides of the carrier, and a relatively insignificant number exhibit only approach reflections.

(S) In Figs. 7b, 8b, 9b, and 10b the total 11-minute doppler-vs-time record has been processed through an equivalent analysis bandwidth of 0.075 Hz, coherently detected, and passed through a low-pass filter with 25-Hz cutoff frequency, which



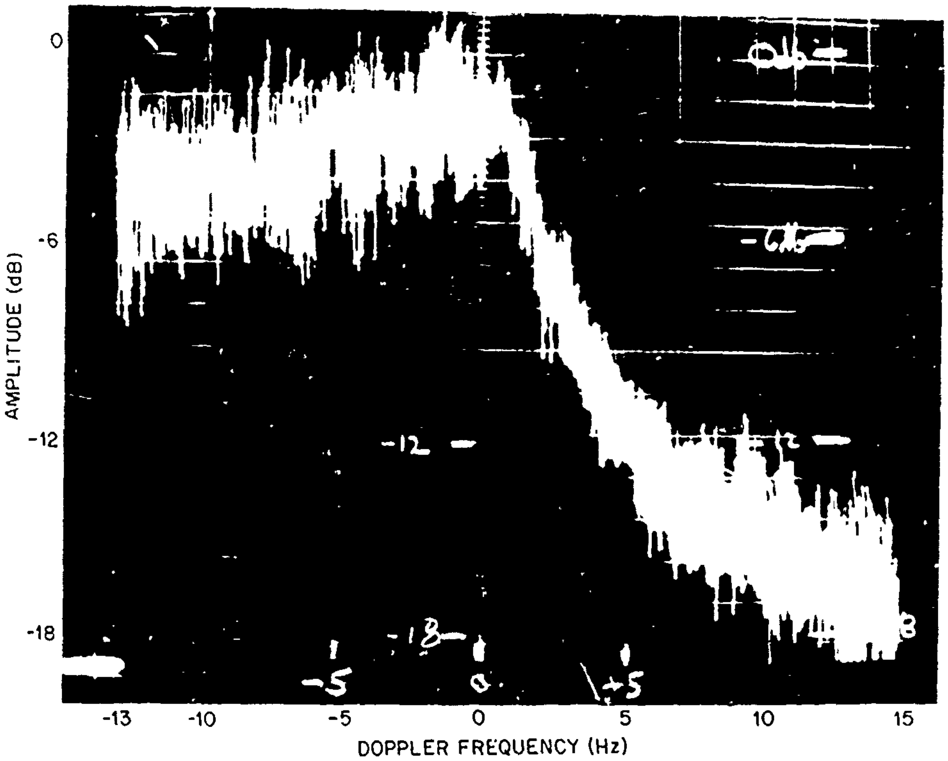
(S) Fig. 7a—An 11-minute offset doppler record of meteor echo distribution with doppler frequency. The doppler zero is at the midpoint of the ordinate, the approach sense is above the zero, and the recede sense is below. The range sample is 277 to 357 n.mi.

corresponds to averaging over the total 11 minutes. The amplitude of the spectral readout is as indicated in dB.

(S) In the spectra records the amplitude curves are similar, with a rather steep rise beginning on the approach side at +15 Hz and coming to maximum value at or slightly beyond (on the recede side of) the doppler zero and then diminishing slowly to a level of from -4 to -8 dB at -13 Hz. The amplitude difference between the spectral amplitude at +5 and at -5 Hz is reasonably constant for the four records at a value of 8 to 10 dB.

(U) It is interesting to compare the shape of the spectral characteristic of Figs. 7b, 8b, 9b and 10b with the theoretical curve of Fig. 5. The resemblance between the theoretically expected amplitude-vs-time behavior and the experimentally determined values is quite good.

(S) Figure 11 is yet another 11-minute doppler-vs-time record taken when the transmitter power had been reduced to 0.073 MW. Even though there are fewer total meteor echoes, the distribution of energy on the two sides of the radar carrier frequency appears the same as in the higher transmitter power records, with recede echoes dominating. Within the range of power levels programmed during the test no significant difference was noted in the distribution of echo energy from the meteor nose echoes.



(S) Fig. 7b—Spectral readout of the 11-minute record of Fig. 7a. The relative amplitude is in dB as marked

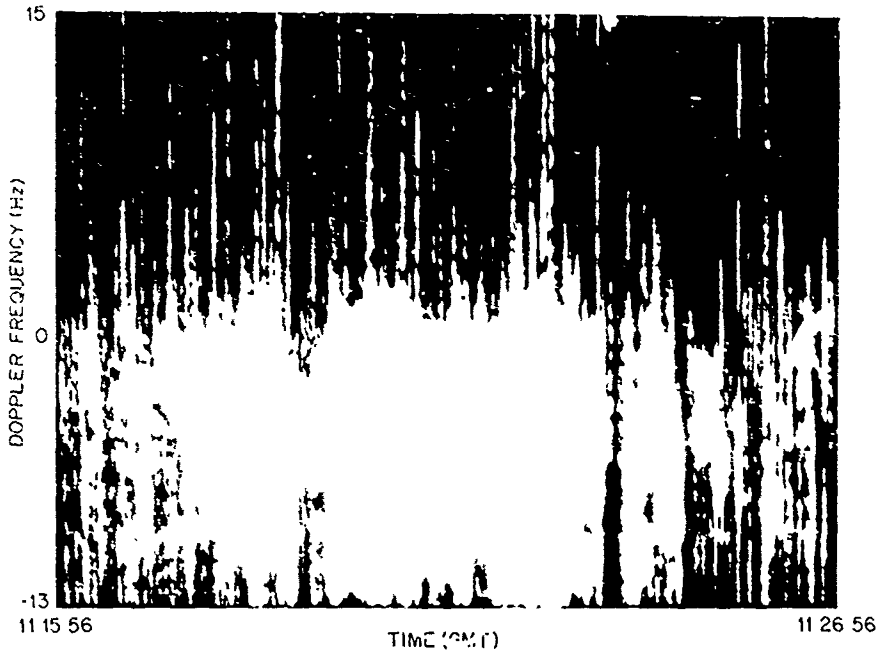
(S) Figure 12a is an offset doppler display as a function of range. The offset frequency is 15 Hz, which gives the doppler zero frequency a midscale on the ordinate. The integration time for the record was 5 seconds. A patch of low-level range-ambiguous clutter is seen on the zero doppler line from 41 to 550 n.mi. Other weaker clutter returns are seen at ranges short of 300 n.mi. The calibration signal of 100 μV (peak to peak) is seen at 400 n.mi. at a doppler of 5 Hz above the carrier.

(S) An explanation is in order regarding the doppler sense of echoes. Before the analysis of Fig. 12a was made, the local oscillator reference frequency was shifted to make recede meteor echoes appear in the upper half of the doppler display instead of the lower half and approach echoes appear in the lower half. The change was made to prevent the spurious signal seen at the bottom of the readout from contaminating or biasing the recede echo domain.

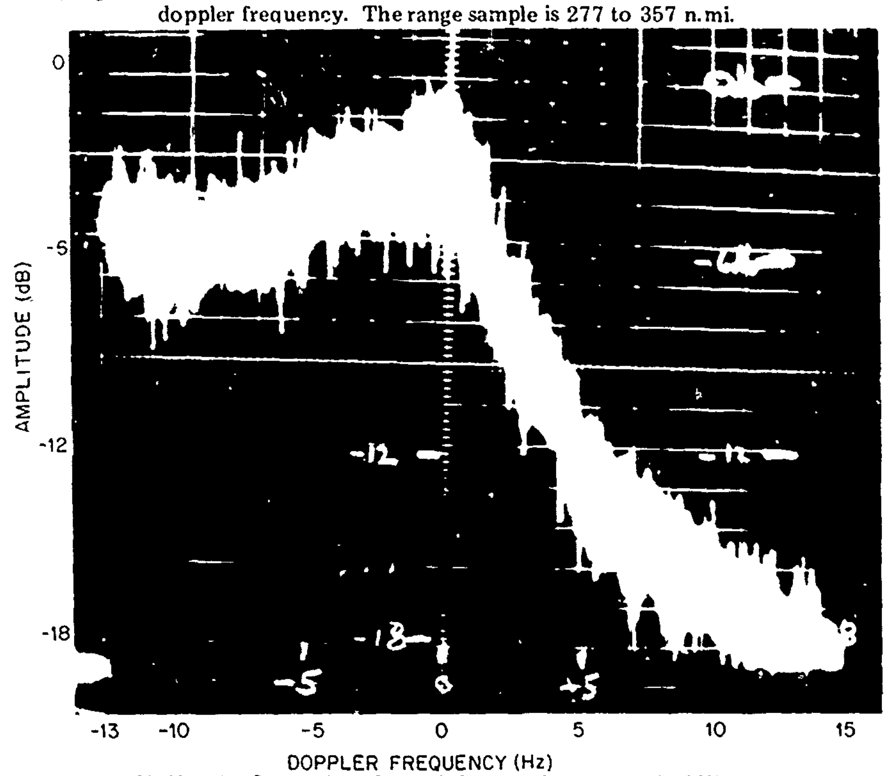
(S) In Figure 12a an intensified range window (168 to 365 n.mi.) is seen overlaying at least four meteors whose dominant echo is on the recede side (above in the figure) of the radar carrier frequency (doppler zero). The range strobe is centered on a meteor at 305 n.mi.

(S) Figure 12b is an amplitude-vs-doppler readout for Fig. 12a. The doppler extent is from +13 Hz (approach) at the left to -15 Hz at the right. The inset amplitude scaling

SECRET-NOFORN
EXCEPT UK

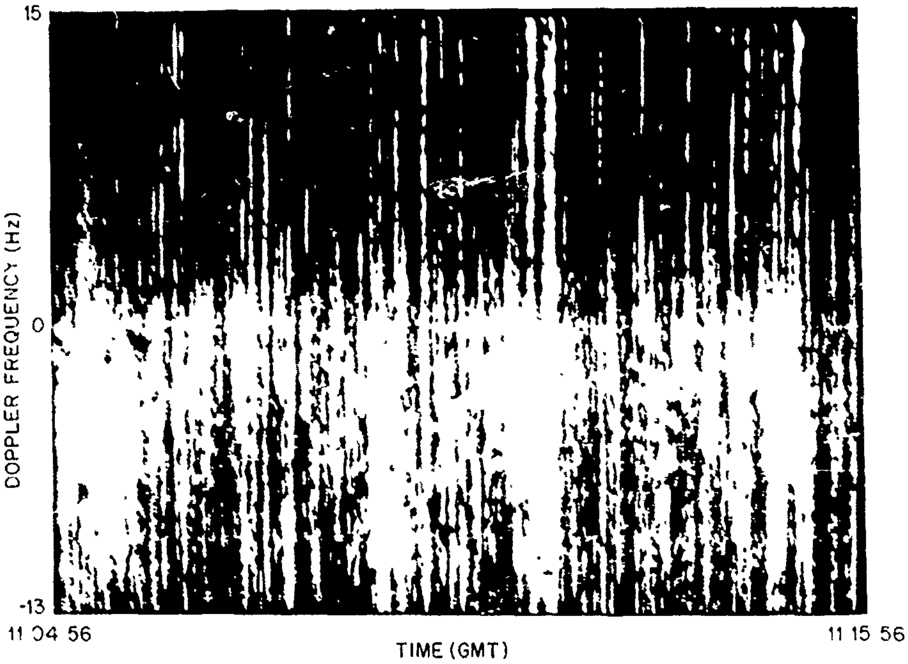


(S) Fig. 8a--An 11-minute offset doppler record of meteor echo distribution with doppler frequency. The range sample is 277 to 357 n.mi.

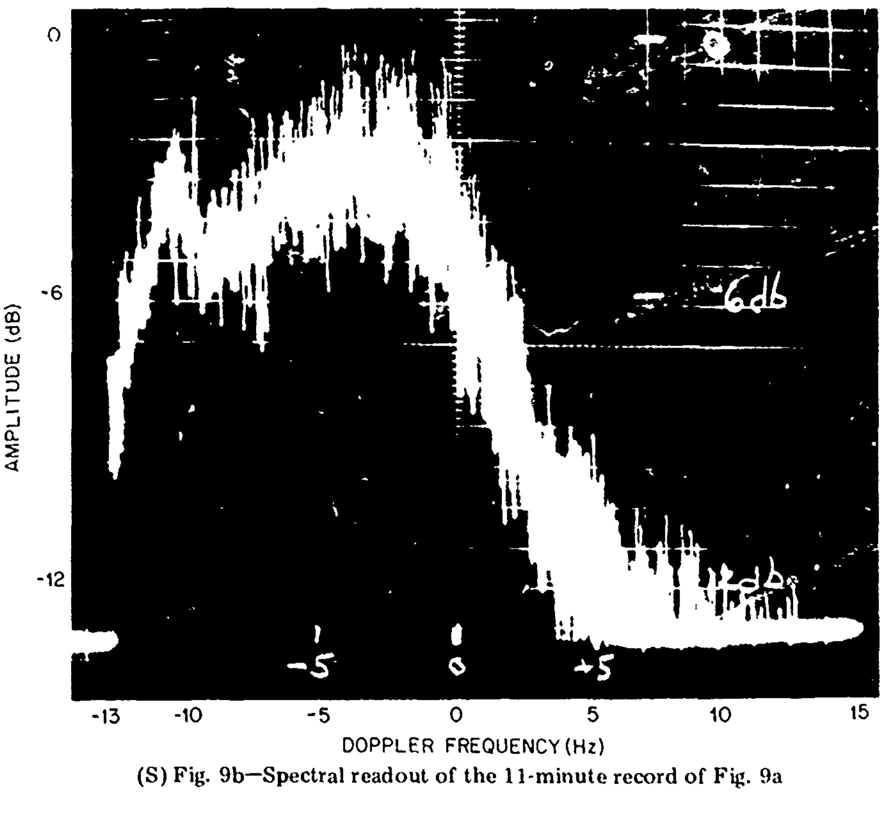


(S) Fig. 8b—Spectral readout of the 11-minute record of Fig. 8a.

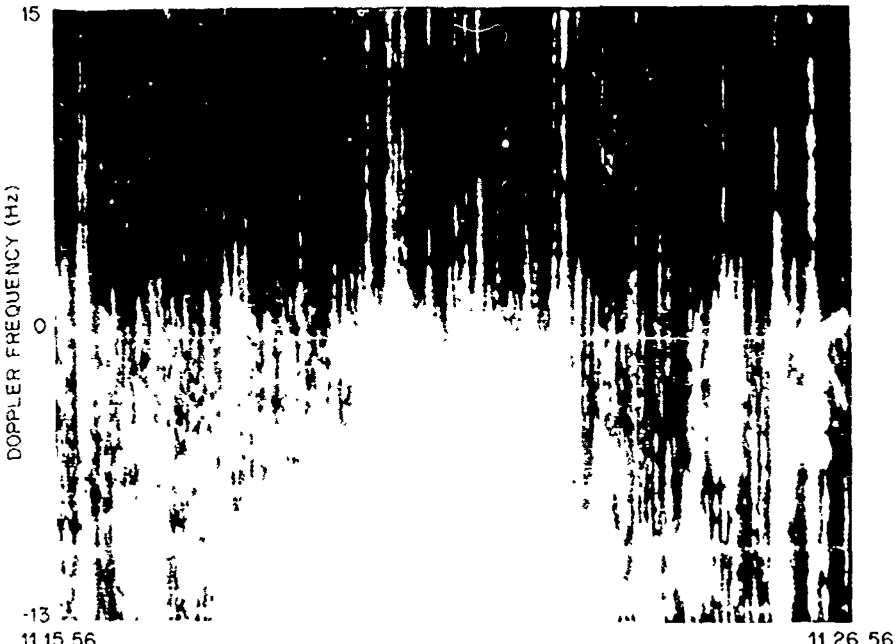
SECRET-NOFORN
EXCEPT UK



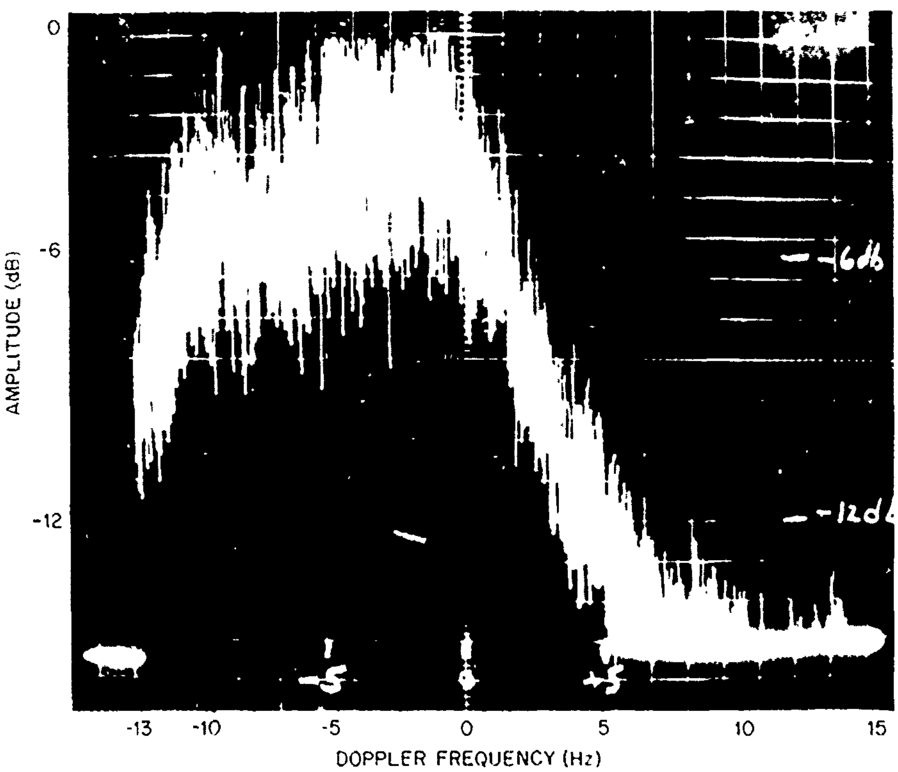
(S) Fig. 9a—An 11-minute offset doppler record of meteor echo distribution with doppler frequency. The range sample is 357 to 437 n.mi.



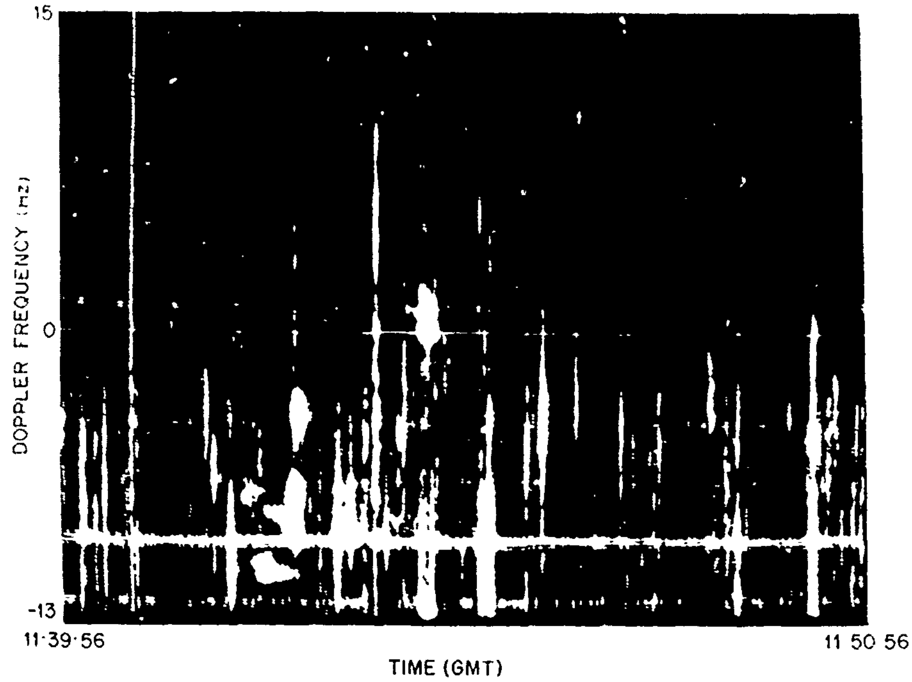
(S) Fig. 9b—Spectral readout of the 11-minute record of Fig. 9a



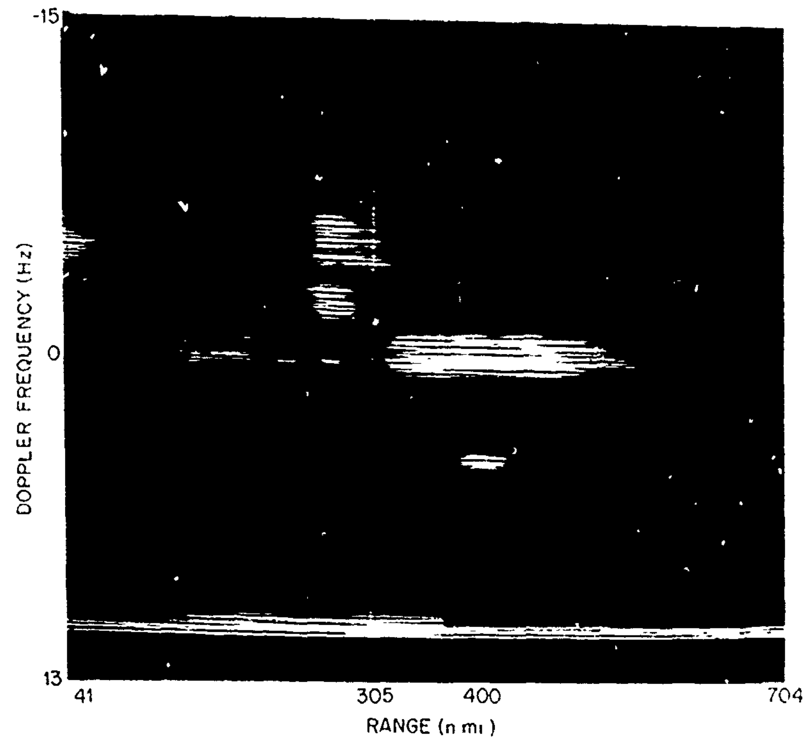
(S) Fig. 10a—An 11-minute offset doppler record of meteor echo distribution with doppler frequency. The range sample is 357 to 437 n.mi.



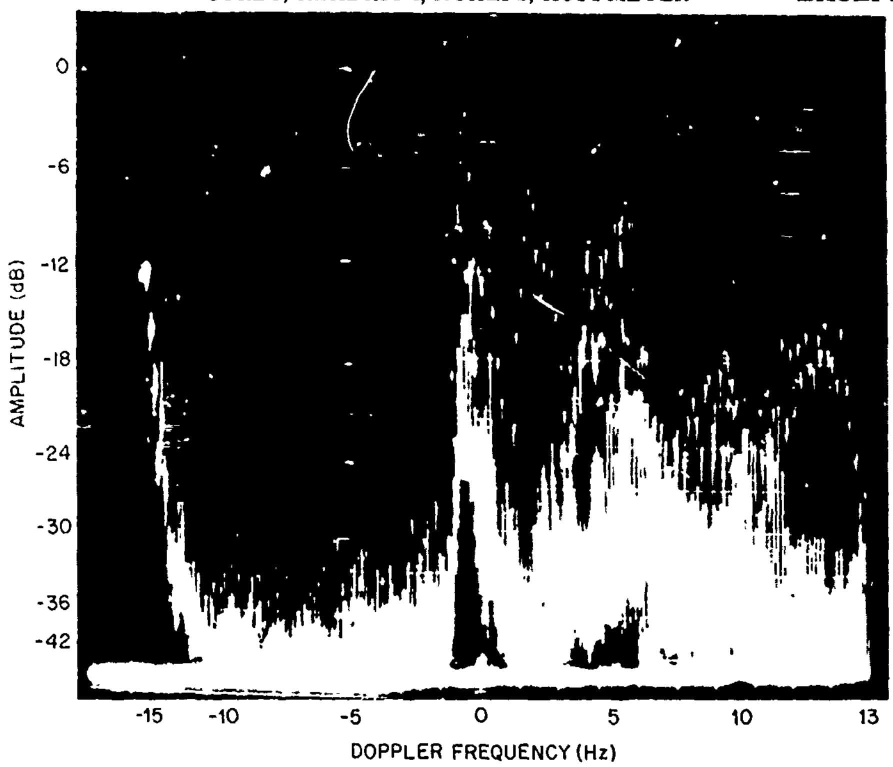
(S) Fig. 10b—Spectral readout of the 11-minute record of Fig. 10a



(S) Fig. 11—An 11-minute offset doppler record of meteor echo distribution with doppler frequency, taken with reduced transmitter power. The range sample is 357 to 437 n.mi.



(S) Fig. 12a—An offset 5-second doppler-versus-range record showing near-range meteors

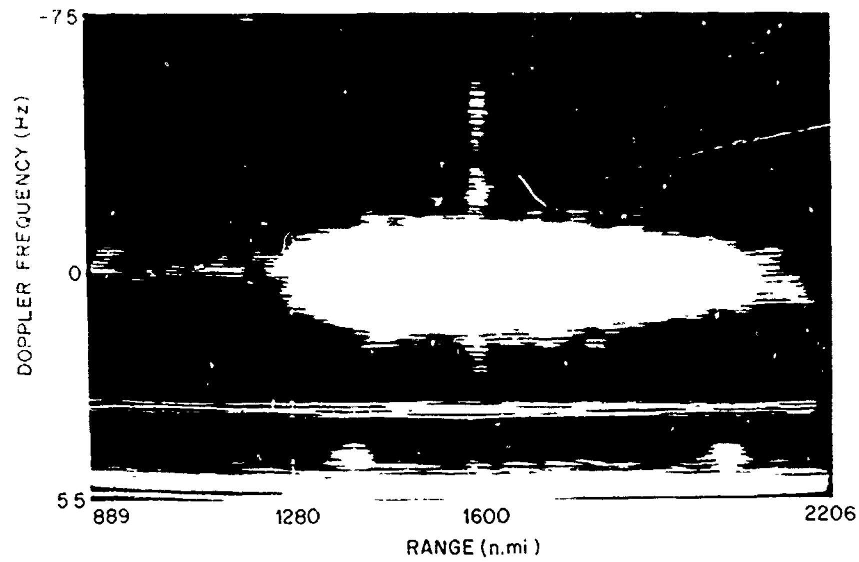


(S) Fig. 12b—Spectral readout of meteor echoes in Fig. 12a. The relative amplitude is in 6-dB steps as indicated. 0 dB is equivalent to a 100 μV (peak to peak) signal.

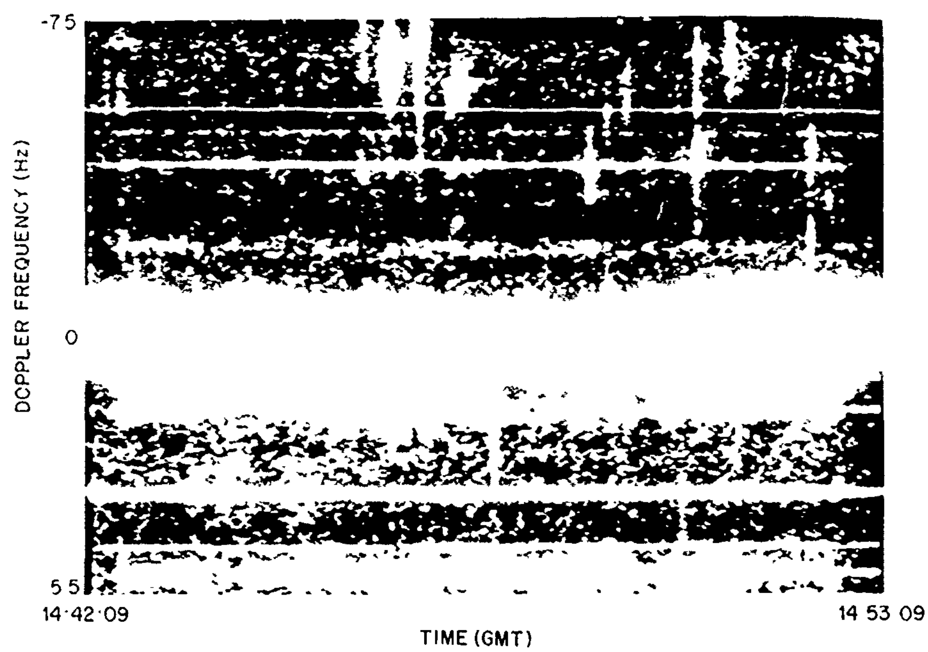
consists of 6-dB steps, with the maximum level corresponding to a 100-μV (peak to peak) calibration signal. During the near-range meteor observations system sensitivity was as good as -148 dBW at times. The amplitude-vs-doppler display to the right of midscale (recede) is a composite of the spectral character of the several meteors in the range window of Fig. 12a. Two of the returns are slightly below 50 μV (peak to peak) in signal strength. There is a rather dramatic difference in signal levels on the two sides of the doppler zero, with the recede echo structures being the larger.

Far-Range Meteor Echoes

(S) As daylight approached on 23 February, ionospheric refraction developed which permitted illumination of meteors at far ranges. Figure 13, an offset-doppler record as a function of range, shows a backscatter pattern with a meteor echo. The pulse-repetition frequency for the far-range look was 30 pps, which allowed unambiguous ranging on the backscatter. The unambiguous doppler extent is thus 13 Hz which has been partitioned into two segments in Fig. 13. Approach dopplers appear below the earth return (centered approximately on the zero doppler line) and recede signals are in evidence above the backscatter. Energy is returned from earth scattering over the region 1280 to 2200 n.mi. The wide-band meteor return occurs at 1600 n.mi. Its doppler sense can be seen to be predominantly recede, with an indication of weaker returns on the approach side.



(S) Fig. 13—An offset 5-second doppler-versus-range record showing a far-range meteor echo along with earth return

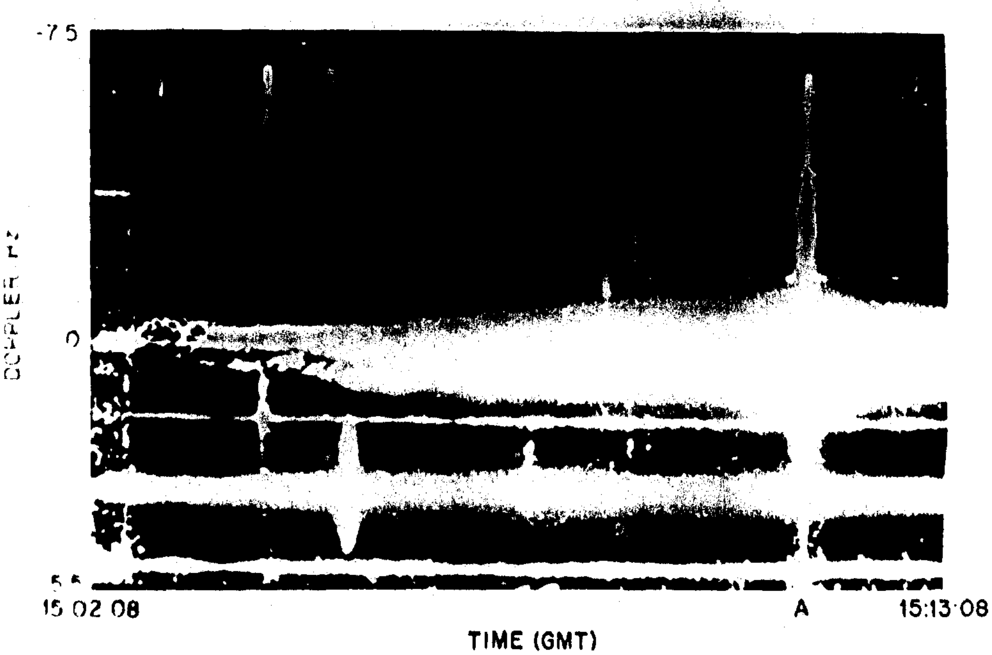


(S) Fig. 14—An 11-minute offset doppler record of far-range meteor echoes and earth return. The range sample is 1318 to 1398 n.mi.

(S) Figure 14 is an 11-minute offset doppler record showing doppler occupancy of far-range meteors. These echoes were collected in an 80-n.mi. range window beginning at

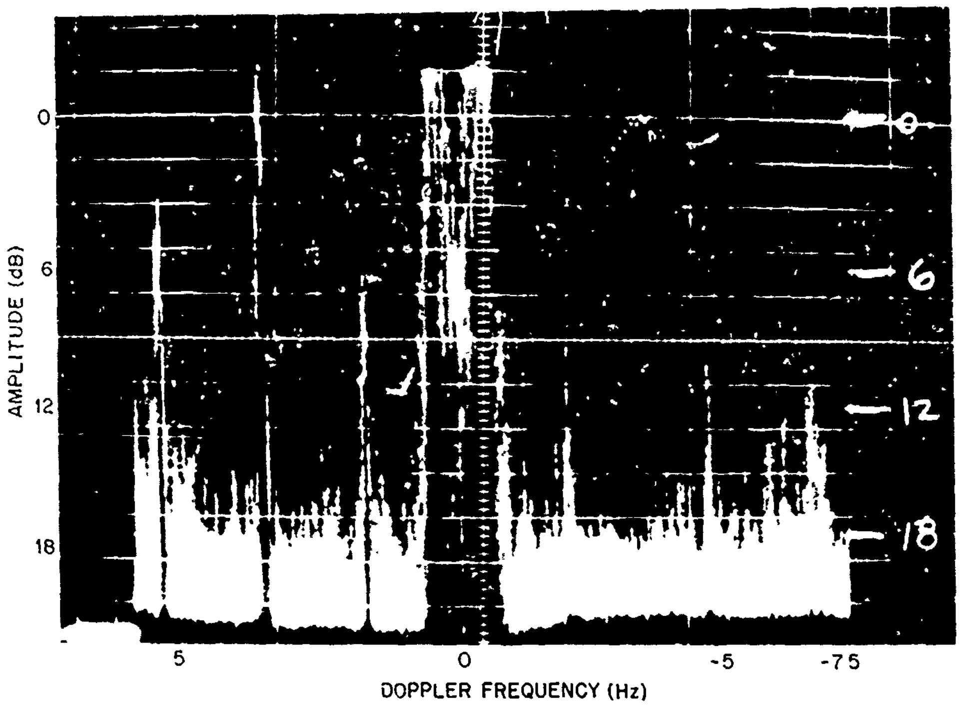
1318 n.mi. The earth return is noted along a line represented by zero doppler. The doppler irregularities in the earth return are due to instabilities in the newly formed refracting ionosphere. The vertical intensifications in the record are meteor nose echoes. It can be seen that they are scattered over the unambiguous doppler extent, of which half is below the clutter and half is above. The echoes on the recede (upper) side seem more pronounced than those on the approach (lower) side. From comparison of Fig. 14 with Fig. 7a it is obvious that the number of echoes is appreciably smaller in the far range for equal observing times.

(S) Figure 15a is an 11-minute record like Fig. 14. The earth-return development commences near the left margin and increases in intensity with increasing record time. The meteor echo showing double sideband energies, designated at point A in the record, is spectrally analyzed in Fig. 15b. A narrow sampling window (time) was used to preclude the inclusion of echoes at other times. Inasmuch as the sampling examines all dopplers, we see responses from the earth return in Fig. 15b in addition to the spectral components due to the meteor echo. The double-response earth echo is the largest echo in the frame. Its pattern appears shifted slightly to the approach side of the doppler zero. This shift is due to the descending motion of the ionosphere for this time of day. The meteor echo can be seen to have energy spread over most of the spectrum.

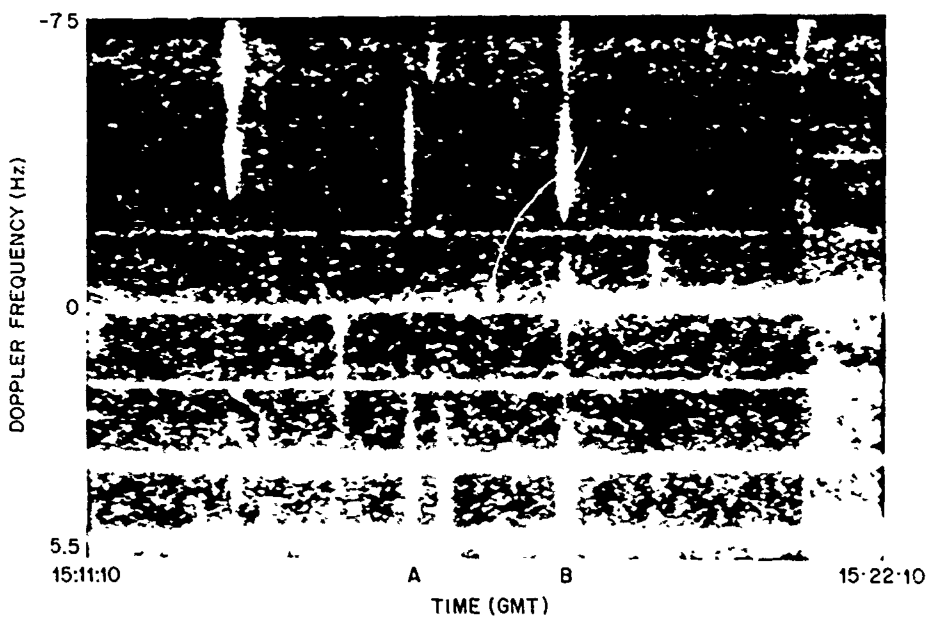


(S) Fig. 15a—An 11-minute offset doppler record of far-range meteor echoes and earth return. Doppler zero is midscale on the ordinate. Recede dopplers are above the doppler zero and approach are below. The range sample is 1258 to 1318 n.mi.

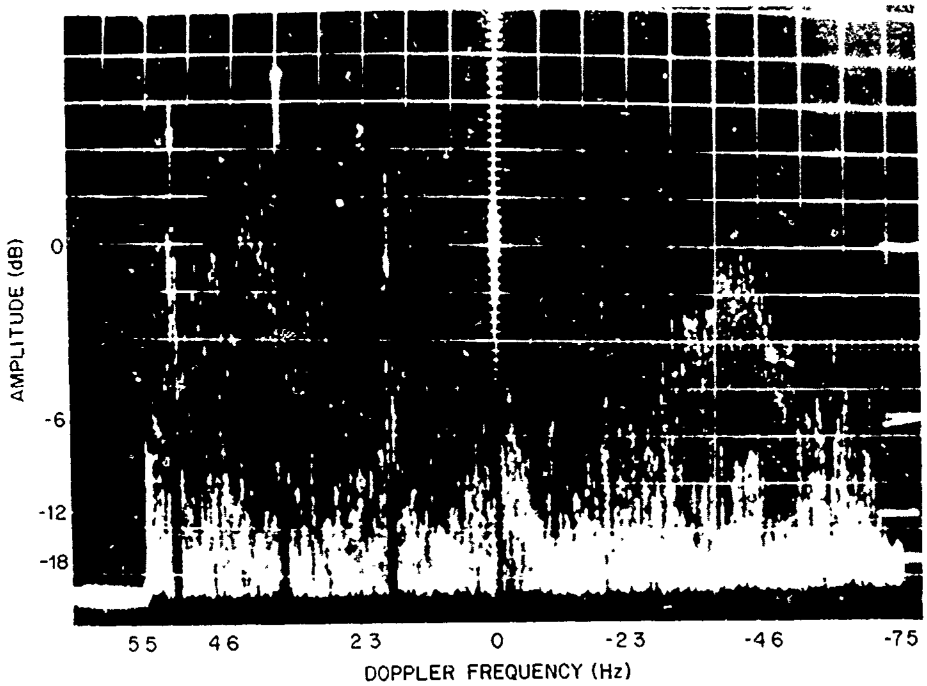
(S) Figure 16a is yet another 11-minute offset doppler record of far-range meteor echoes. Only a weak earth echo is apparent in this frame. The meteor echoes at points A and B have been spectrally analyzed in Figs. 16b and 16c respectively. In both of these examples the meteor return yields spectral components on both sides of doppler zero; this is in contrast to the majority of meteor nose echoes, which show a preference for recede dopplers. It is obvious from examining (over a 7.5-Hz partition in each direction) the meteor echoes in the far range that they can be spectrally dispersive.



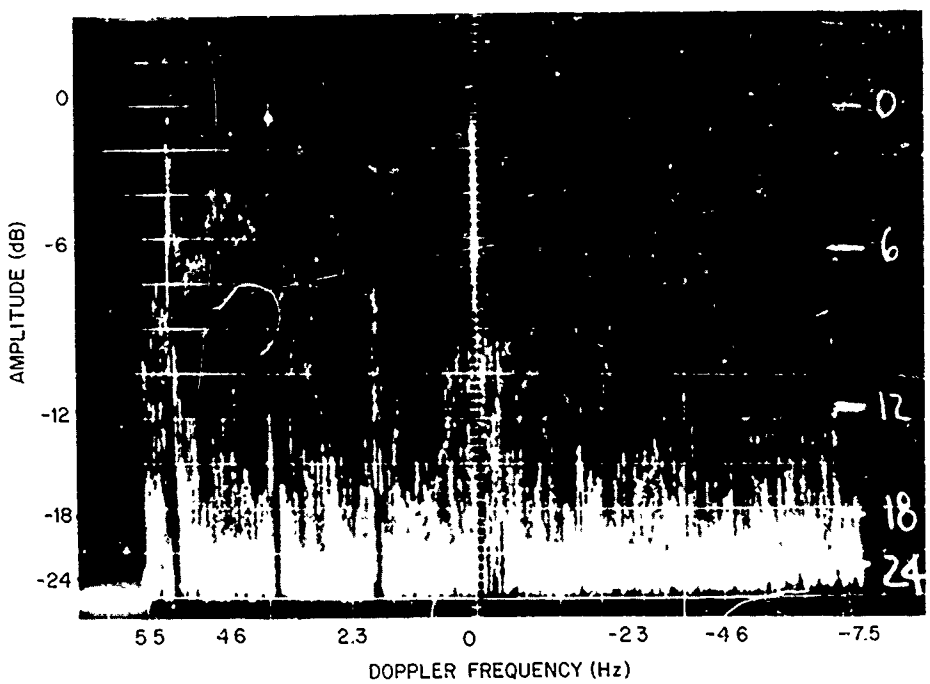
(S) Fig. 15b—Spectral readout for the meteor echo at point A in Fig. 15a. The doppler extent is from +5.5 Hz on the left to -7.5 Hz on the right



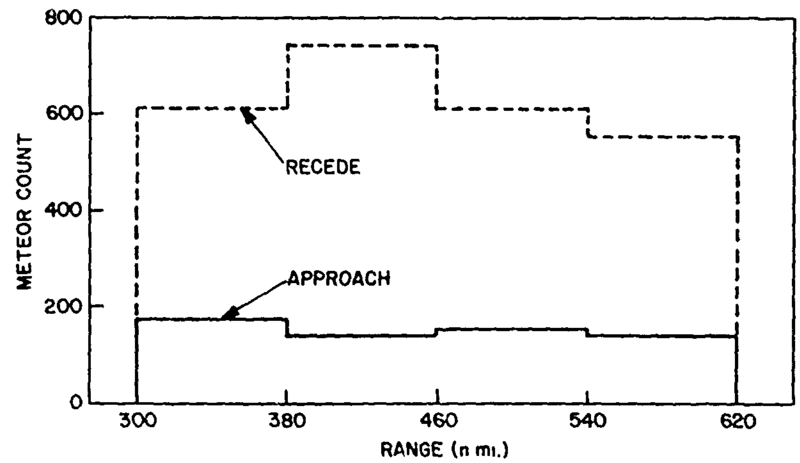
(S) Fig. 16a—An 11-minute offset doppler record of far-range meteor echoes and weak earth return. The range sample is 1198 to 1258 n.mi.



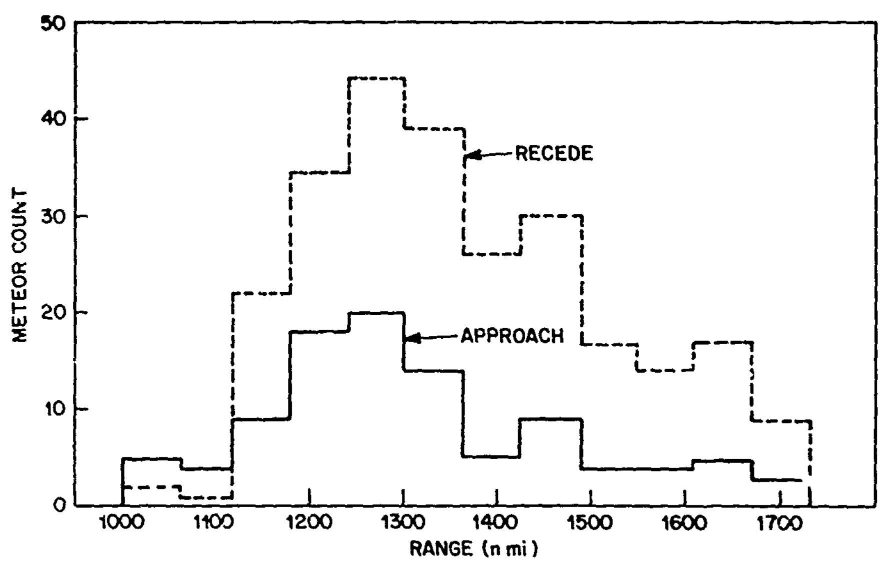
(S) Fig. 16b—Spectral readout for the meteor echo at point A in Fig. 16a



(S) Fig 16c—Spectral readout for the meteor echo at point B in Fig. 16a



(a) Near range (3151 echoes)



(b) Far range (355 echoes)

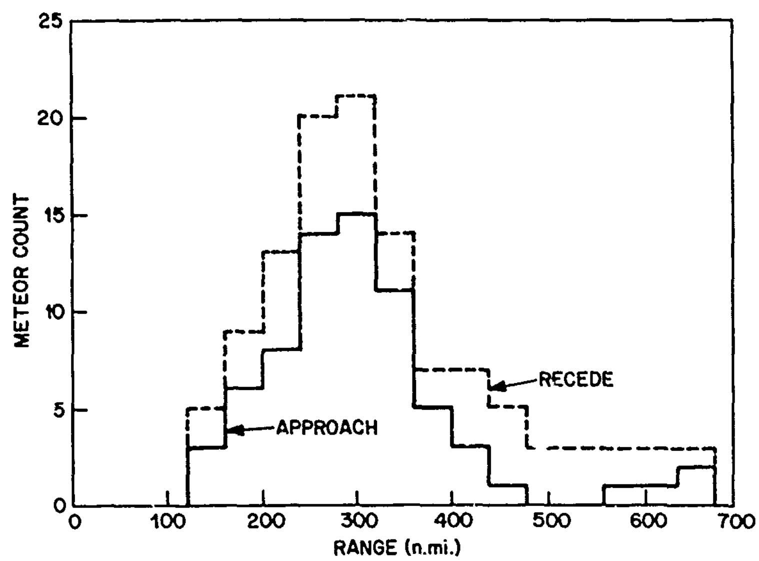
(C) Fig. 17—Meteor echoes as determined with the Madre radar on 23 February 1973

Spectral Character of Meteor-Nose Echoes—Summary

(S) In an attempt to determine the population of recede and approach echoes the meteor records for near-range and far-range observations were scaled for a count. Figure 17 gives a count summary for the Madre system measurements of 23 February. The near-range counts were scaled over 80-n.mi. range bins. From Fig. 17a it can be seen that the ratio of recede echoes to approach is approximately 3:1. From the far-range meteor

summary given in Fig. 17b, the ratio of recede to approach is approximately 2.5:1. These counts were made without regard to strength of echo. On the basis of observations the predominant energy is in the recede region. A simple ratio of counts may be misleading if an attempt is made to infer total-echo-energy doppler distribution.

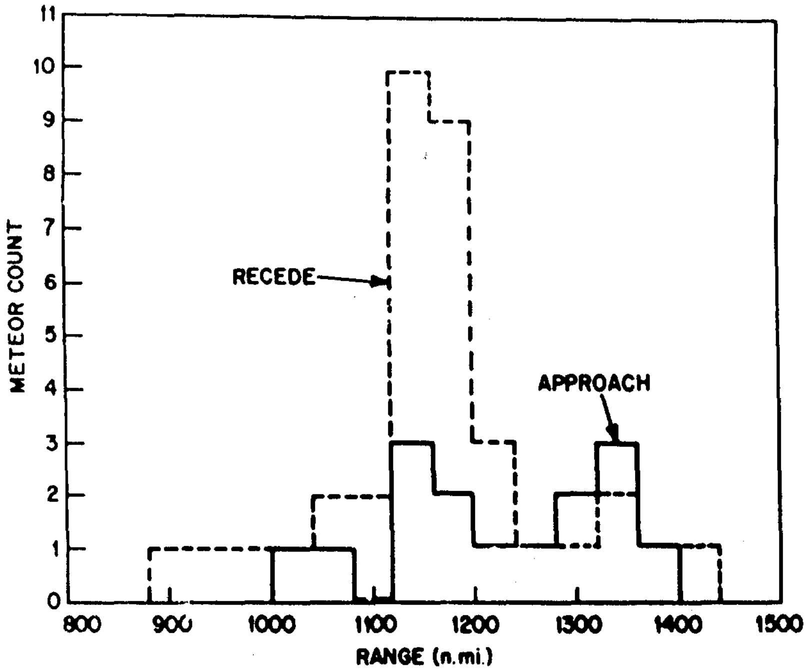
(S) In addition to scaling the NRL results, an FPS-95 data tape (tape 513) was analyzed for a partitioned count and a ratio of recede to approach echoes for returns in the near region as well as the far region. Figure 18a gives the results of counting the near-range meteors in 40-mile range bins from 120 n.mi. to 680 n.mi. Of the 175 echoes 116 appeared as recede targets and 59 were approach targets. The ratio of recede to approach is approximately 2:1. Figure 18b gives the results of far-range meteor scaling. Of this smaller sample of 51 echoes, 36 were recede echoes and 15 were approach echoes, thus giving a recede-to-approach ratio of close to 2.5:1.



(a) Near range (175 echoes)
(S) Fig. 18—Meteor echoes as determined with the FPS-95 radar on 15 March 1972

RECAPITULATION AND FURTHER COMMENTS

(S) It is appropriate at this point to compare the theoretical characteristics of meteor echoes as assessed from the literature and the experimental characteristics from Madre and FPS-95 observations with the description of the FPS-95 noise given in the Background section to see which features coincide for the two phenomena. Salient features of this comparison are discussed below.



(b) Far range (51 echoes)

(S) Fig. 18—(Continued)

(S) • The noise varies markedly with range; it is not uniformly distributed over all range bins as noise should be. If the noise is range discrete, it is likely not noise but a subtle echo. Meteor echoes are not uniformly distributed over the range base, because they occur at discrete locations in the meteor region (100-km height) at slant ranges out to the line-of-sight tangent ray and at one or more regions beyond the first ionospheric refraction. This investigation definitely confirms the meteor echoes to be localized in range and not uniformly distributed.

(S) • Range-related noise is seen in different seasons, at different times of the day, in various beams, on both polarizations, and at various operating frequencies. Meteors are an ever-present natural reflector of electromagnetic energy. It is therefore no surprise that whatever portion of the FPS-95 noise attributable to meteors would evidence a pattern of being ever present (over discrete range regions).

(S) • In addition it is quite conceivable that the FPS-95 radar, being at a high magnetic latitude, might experience echoes from spread *F*, from auroral scatterers, and from field-aligned ionization at orthogonal intersection of the radar ray with the geomagnetic field. Wide-band signals outside normal clutter dopplers may be elicited from magnetic-field-aligned ionization at or near the geomagnetic equator. Hudnall [20] has observed such echoes, on at least one occasion, with the FPS-95 radar. These echoes, which do exceed the spectral limits of normal clutter and are generated at long distances (> 6000 n.mi.), compete strongly for doppler range space in a high-PRF environment. NRL has observed these echoes consistently at 5000 to 6000 n.mi. from the Chesapeake Bay installation. They can in fact hamper aircraft detections at much closer ranges (1000

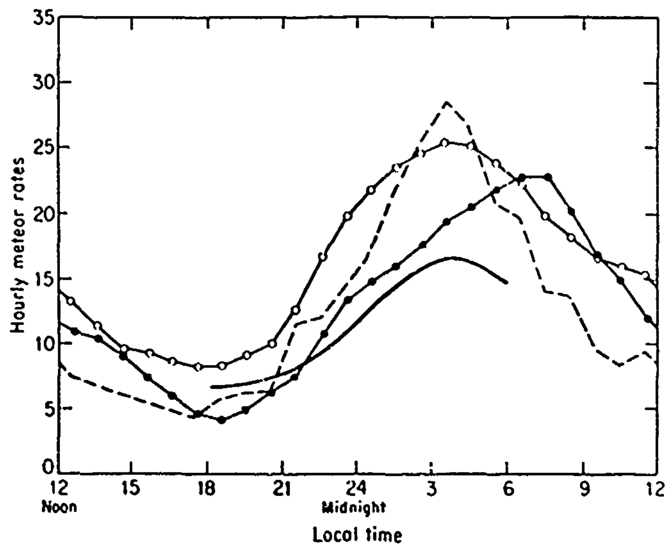
to 1500 n.mi.). All such echoes should be identifiable in a radar with sufficient flexibility in range sampling. These echoes should exhibit discrete appearance in the range and doppler profiles. Moderately spread clutter echoes are regularly seen at dawn and dusk when the ionization of the ionosphere increases and diminishes. These match the range extent of the clutter; they do not lead the clutter in range.

(S) • The noise tends somewhat to be proportional to ground clutter amplitude, hence the name clutter-related noise. This particular aspect of the problem has not been directly addressed in this investigation, but some intuitive comments are in order. First, the amplitude of the clutter echo is a function of the loss over the path both in the refracting layer as well as in the D region. If the loss is low, the clutter will be enhanced. By the same token the energy density existing at meteoric heights, at ranges in advance of the clutter echo, will also be above normal. This will increase the meteor echo rate on the system. It seems reasonable that the meteor echo flux will essentially ride up and down with clutter echo amplitude, as that in turn is a descriptor of the existing propagation path. As a second matter, consideration should be given to the possibility that meteor echoes as well as clutter will generate spurious modulation products as a function of nonlinearities in the radar-antenna ground screen. This mechanism, presently being studied by Rafuse [19], would not differentiate between the incoming signals, along a given ray path, as to whether they are meteor echoes or earth returns. Meteor echo amplitudes as well as earth echo amplitudes are both a function of illuminating energy density. The same ray that collects a ground reflection is also prone to fetch a meteor echo when it penetrates the E layer. The propagation path loss should affect the clutter and nearby meteor echo amplitudes alike.

(S) • Energy is spread into doppler domains well removed from the clutter spectrum. It is the nature of the meteor echo that it should possess doppler content beyond the normal bandwidth of normal clutter echoes. During trail formation the echo evidences approach/recede bandwidth occupancies in accordance with the diffraction-pattern theory [10]. Reflections from the trail after formation often show motion at velocities consistent with E-layer winds, which again places the echo energy out of the bandwidth of the normal clutter.

(S) • The noise level is asymmetric between approaching and receding doppler bins. The literature searched and the experimental evidence examined bear witness to the fact that the echo energy received from the meteor nose is distributed asymmetrically across the available doppler bandwidth, with recede energy dominating over approach energy. Confirmation of this unequal energy partition was obtained at transmitter pulse-power levels from 2.3 MW to 73 kW. FPS-95 radar engineers have indicated that the spectral asymmetrical distribution shows recede energy to dominate in the near range and again in the noise that precedes the clutter, but beyond the clutter leading edge there is no predisposition to asymmetry. In the Madre data taken 23 February, as witnessed by Fig. 17b, the far-range meteors persist in unequal division of spectral energy beyond the leading edge (1280 n.mi.) of the clutter. It appears from the sampling of 355 echoes in the far range that there is no change in spectral energy distribution at the clutter leading edge.

(S) In general, a meteor is classified as being either a shower meteor or a sporadic meteor [21]. The shower meteor is associated with one of the many showers that the earth passes through annually. A meteor in a shower is generally of a larger mass than a sporadic meteor. The radiant (apparent source in the celestial sphere) is reasonably well known for the shower meteors. Their velocity spread from shower to shower is well known. Radiants and pre-event velocities for sporadic meteors are not known. The geometry (beam position) could be important for optimum viewing (or disregard) of meteors in a shower stream. On the other hand, sporadic meteors should be available across all beam positions. The population of a given-size meteor is approximately proportional to the reciprocal of its mass. The FPS-95 radar system is in all likelihood sufficiently sensitive to see echoes produced by very small meteors (electron line densities of 10^{11} to 10^{12}), of which there are 10^{11} impacting the earth's atmosphere per day [5]. In the experiment of 23 February the echo rate was approximately one echo per second somewhere between 120 and 680 n.mi. Measurements made with the Madre system were only down to a level of -148 dBW, whereas the desired noise floor of the FPS-95 is -178 dBW. Most of the noise that plagues the FPS-95 is below the detection threshold of the Madre radar. One can only speculate how many more weaker echoes would have been seen in the Madre data at near and far ranges if an additional 30-dB sensitivity had been available. The sporadic-meteor population is substantial enough to give an appreciable number of echoes below the -148 dBW level on the FPS-95 radar. Figure 19, due to McKinley [9], is the diurnal behavior of meteor echo rates for several sensing methods. The general tread shown is that there is less than an order of magnitude change (perhaps 2 to 5) in the meteor rates between 0600 hours and 1800 hours. Striking diurnal patterns in FPS-95 noise have not been noticed. One wonders if the system is not saturated, at least in the near region, at 1800 hours and if the modest increase that takes place during the night is imperceptible due to preexisting saturation.



(U) Fig. 19—The mean daily variation of meteor rates for several sensing methods

(S) From the foregoing review of the FPS-95 range-related noise and its comparison with the features of meteor-nose echoes, it is concluded that meteors are likely a strong contributor to the observed noise. Reasonable coincidences exist between all paired characteristics of the RRN and meteor echoes. The next section discusses procedures to permit operation in an environment of natural echoes (meteors).

RECOMMENDATIONS

(S) Since NRL commenced its OTH investigations in the mid-1950's, meteor echoes have been an ever-present natural echo. There is no easy way to eliminate them completely, but judicious choice of operating parameters can lessen their impact on detection sensitivities. The meteor echo falls into the general classes: meteor-nose echo and meteor-trail echo.

(S) From NRL experience it can be said that a meteor-nose echo possessing a dispersive doppler signature may resemble an echo from a thrusting missile stage. A discriminant between the two would be the duration of the echo with the meteor-nose echo lasting no longer than the radar integration period whereas the missile-burn echo may persist for several integration periods.

(S) The meteor-trail echo initially may possess moderately broad doppler character which over a period of many seconds or even minutes becomes perhaps as spectrally compact as an aircraft echo. At times a meteor-trail echo may be confused with an aircraft echo on the basis of a single-integration-period look. Only a minority of meteors yield this type of echo. Time again provides the discrimination between the two; the genuine aircraft target will build a coherent range-vs-time track and the meteor echo will eventually be dismissed as false.

(S) The use of 5- and 10-second integration periods with Madre have permitted the consistent OTH detection of aircraft and missiles without compromising degradation in performance due to meteor trails.

(S) If we assume the meteor echoes will ever be with an OTH radar, certain suggestions can be made concerning FPS-95 radar operation that would permit alleviation and/or accommodation of meteor echoes in order that detection performance not be adversely affected. Some of the changes recommended are modifications to existing hardware/software, and others deal with operating procedures. Some of these changes may be in the process of being implemented at this writing. The hardware/software recommendations are:

- Permit 250-μs-pulse-width operation at all PRF's including 10 pps.

- Adapt signal processing to accomplish full spectral analysis of designated range window(s) at 10 pps.

- Implement three or more bits of gray-scale intensification to permit better target-signature discrimination.

- Enhance the flexibility of the threshold control, enabling the setting to be changed dynamically within a given integration period.

The operational-procedure recommendations are:

- Use a short pulse (250 μs) to segment ranges of meteor echoes. Identify and spectrally analyze single and multiple meteors to determine their coincidence in character with that of the range-related noise.

- Implement narrow range sampling to preclude meteor echo energy from falling in the same range interval as a target.

- Implement shorter integration periods for larger-cross-section targets (missiles) to avoid keeping short-lived meteor echoes over long integration periods; that is, do not accumulate meteor echoes that will compete against man-made targets.

- For range-ambiguous man-made targets make judicious choice of the PRF to avoid folding the target region into a high-meteor-density region.

- Critically examine the spectral character of the meteor echo, compare it with that of an aircraft and missile, and use the differences to establish target recognition criteria in the presence of meteor activity.

- Learn to ignore the meteor echo and to see through it to ferret out the unique signatures of man-made targets.

ACKNOWLEDGMENTS

(U) The authors extend their appreciation to other members of the Branch, to Mrs. Etzel and Mrs. Martin for typing the report manuscript, to Mr. Ferrell for his cooperation in collecting the meteor echo data, and to Mr. Lieberman for his patience in scaling the meteor counts.

REFERENCES

1. "Impressions of the Operating Environment Gleaned During a Visit to the AN/FPS-95 Radar Site, 6-12 December 1972," Frank Utley, NRL internal document (Secret).
2. "Discussions with FPS-95 Mission Director 12 December 1972," Frank Utley, Consultative Services Report NRL internal document (Secret).
3. Personal communication from Ed Key, the Mitre Corp., 25 Jan. 1972 (Secret).
4. "Effects of Range-Related Noise Upon System Performance," memorandum from R. I. Millar (Mitre Corp.), Orfordness, to R. F. Shackford (Mitre Corp.) Bedford, Mass., 21 Nov. 1972 (Secret).

5. L. A. Manning and V. R. Eshleman, "Meteors in the Ionosphere," Proceedings of the IRE 47, 186-199 (Feb. 1959).

6. J. A. Clegg and I. A. Davidson, "A Radio Echo Method for the Measurement of the Heights of the Reflecting Points of Meteor Trails," Philosophical Magazine 41, 77-85 (1950).

7. J. S. Hey and G. S. Stewart, "Radar Observations of Meteors," Proceedings of the Physical Society 59 (Pt. 5), 858-883 (Sept. 1, 1947).

8. T. R. Kaiser, "Theory of the Meteor Height Distribution Obtained from Radio-Echo Observations," Royal Astronomical Soc. Monthly Notices 114 (No. 1), 39-62 (1954).

9. D. W. R. McKinley, *Meteor Science and Engineering*, McGraw-Hill, New York, 1961.

10. A. C. B. Lovell, *Meteor Astronomy*, Oxford at the Clarendon Press, 1954.

11. D. W. R. McKinley and P. M. Millman, "A Phenomenological Theory of Radar Echoes from Meteors," Proceedings of the IRE 37, 364-375 (Apr. 1949).

12. F. H. Utley, "On the Feasibility of Instantaneous MUF Determination from Observations of Far Range Meteor Trail Echoes," submitted to the Faculty of the School of Engineering of the George Washington University in partial satisfaction of the requirements for the degree of Master of Science in Engineering, Feb. 1962.

13. J. T. deBettencourt, and W. A. Whitcraft, Jr., "Long Range Meteoric Echoes Via F-Layer Reflections," Transactions of the IRE AP-4, 72-76 (Jan. 1956).

14. W. L. Hartsfield, "Observations of Distant Meteor-Trail Echoes Followed by Ground Scatter," Journal of Geophysical Research 60 (No. 1), 53-56 (Mar. 1955).

15. P. B. Gallagher and A. M. Peterson, "The Contribution of Meteors to Long-Range Backscatter," abstract in Transactions of the IRE AP-3, 153 (1955). (Paper presented at IRE-URSI Symposium, May 2-5, 1955, Washington, D.C.)

16. J. G. Davies and C. D. Ellyett, "The Diffraction of Radio Waves from Meteor Trails and the Measurement of Meteor Velocities," Philosophical Magazine 40, 614-626 (1949).

17. G. S. Hawkins and J. C. Brown, "A Comprehensive Study of the Characteristics of Meteor Echoes-I," Smithsonian Astrophysical Observatory Special Report 254, 30 Oct. 1967.

18. L. A. Manning, O. G. Villard, Jr., and A. M. Peterson, "Radio Doppler Investigation of Meteoric Heights and Velocities," Journal of Applied Physics 20, 475-479 (May 1949).

19. Personal communication from Dr. Robert Rafuse (Secret).

20. Personal communication from James Hudnall, NRL scientist at the FPS-95 site (Secret).

21. F. G. Watson, *Between the Planets*, Blakiston, Philadelphia, 1941; revised edition, Harvard Univ. Press, Cambridge, 1956.

MEMORANDUM

20 February 1997

Subj: Document Declassification

Ref: (1) Code 5309 Memorandum of 29 Jan. 1997
(2) Distribution Statements for Technical Publications NRL/PU/5230-95-293

Encl: (a) Code 5309 Memorandum of 29 Jan. 1997
(b) List of old Code 5320 Reports
(c) List of old Code 5320 Memorandum Reports

1. In Enclosure (a) it was recommended that the following reports be declassified, four reports have been added to the original list:

Formal: 5589, 5811, 5824, 5825, 5849, 5862, 5875, 5881, 5903, 5962, 6015, 6079, 6148, 6198, 6272, 6371, 6476, 6479, 6485, 6507, 6508, 6568, 6590, 6611, 6731, 6866, 7044, 7051, 7059, 7350, 7428, 7500, 7638, 7655. Add 7684, 7692.

Memo: 1251, 1287, 1316, 1422, [redacted], 1500, 1527, 1537, 1540, 1567, 1637, 1647, 1727, 1758, 1787, 1789, 1790, 1811, 1817, 1823, 1885, 1939, 1981, 2135, 2624, 2701, 2645, 2721, 2722, 2723, 2766. Add 2265, 2715.

The recommended distribution statement for the these reports is: **Approved for public release; distribution is unlimited.**

2. The above reports are included in the listings of enclosures (b) and (c) and were selected because of familiarity with the contents. The rest of these documents very likely should receive the same treatment.

J. M. Headrick
J. M. Headrick
Code 5309

Copy:
Code 1221 — CR OK 7/2/97
Code 5300
Code 5320
Code 5324